Stand structure and yield of the mixed white poplar and black locust plantations on sandy ridges between the Danube and Tisza rivers in Hungary

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Abstract: The paper deals with the stand structure and yield of black locust (*Robinia pseudoacacia* L.) forests mixed with white (*Populus alba* L.) in various proportions, partly applying a new methodological approach. The main stand structure and yield factors were determined separately for each species, measured stem by stem, using the volume functions prepared for each species. The ratio of the volumes of the species (A and B) in mixed and in pure stands (based on volume tables) was determined. A close relationship has been found between the ratio by relative total volume and the proportion (by the number of stems) of the species. The relative surplus in the volume of the mixed stands varied between 1.24-1.55 at the age of 16 compared to the control, i.e. the yield of pure stands of the species concerned. The trial has also proven that if two species have a fast initial growth rate and a similar rotation age, they can be planted in mixed stands resulting in mutual advantages.

Keywords: Mixed stands; *Robinia pseudoacacia* L.; *Populus alba* L.; Stand structure; Yield

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Introduction

The recent guidelines of primary forest production are generally aimed at the establishment of pure stands. However, mixed stands may also provide advantages that may justify the mixed planting and cultivation of two or three species, given the proper ecological conditions. Mixing has mainly ecological and biological advantages, but in a narrower sense it may also have a strong positive effect on yield and economic efficiency. In addition to wood production purposes, the non-material role and importance of mixed forests (improvement of the environment and the satisfaction of social expectations, etc.) is also increasing. The scientific study of mixed forests as specific biocoenoses and particularly the study of their main component (i.e. stand structure) is a much more complex task than that of pure stands. This partly explains why only limited efforts were made until now to quantify the growth and yield relationships of mixed stands and to compare the results with pure stands, although the advantages of mixed forests are already known.

The professionals have started the description of the species composition of mixed forests at the end of the 18th century. Oak was studied first, followed by the admixed tree species after regeneration. Later other species and their mixes were also studied.

There was a shift starting in the middle of the 19th century from the earlier established large monoculture forests back to mixed forests (Heyer 1854). Analyses made in Central Europe have shown that the volume production of mixed spruce and Scots pine stands exceeds that of pure ones (Schilling 1925, Busse 1931). A mixed forest of birch and spruce (40%:60%) has provided a greater total yield than the same proportion of these species in pure stands (Lappi-Sappala 1930). Mixed beech and spruce forests give a higher yield at good sites than unmixed spruce forests. The contrary of this is true at poor sites where mixed stands show lower yields (Wiedemann 1943).

According to the studies carried out in Central Europe, the admixing of birch in spruce forests did not reduce the yield of spruce (Fiedler 1966). Assmann (1970) paid great attention to the study of mixed stands in his book, titled The Principles of Forest Yield Study. Although it is almost impossible to define comparable pure and mixed experimental plots (plots made up of the species of pure stands), the main finding of the author is that mixing results in a greater total yield.

The choice between mixed or pure stands is a complex issue depending on many criteria. Mixed stands are often more resistant to pests and have a higher production level than pure ones. In most cases, the total yield of mixed stands exceeds that of light-demanding tree species grown in monoculture (Smith 1986).

Growth models based on the growth models of individual trees have also been developed for mixed hard broad-leaved forests of the Appalachian mountains and for yield forecasting in thinned (this is a novelty) birch-spruce stands in Sweden (Harrison *et al.* 1986; Tham 1988). Their stand growth simulation is based on modeling the spatial position

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of trees, distribution of their diameter, the height-diameter function, and on modeling of the growth conditions of trees (including the expected effect of thinning and other factors).

Two volumes have recently resulted in a great step forward in the modeling of the structure and yield of mixed stands (Cannel, Malcolm, Robinson ed. 1992, Costa, Preuhsler ed. 1994), summarizing the latest research work and results on this subject.

Methods for determining the volume and forecasting the yield of mixed stands

The yield of stands and its absolute value at a given age are determined by the complex interaction of environmental and stand structure relationships. Stand structure and structure formation have a causal relationship.

Changes in the growth conditions of dominant and co-dominant trees in height forming the main crop have a key role in determining the volume of stands. The comparison of the main structural factors and indicators relating to individual trees also serve as a base for the study of the conditions.

One of the most often used methods for calculating the volume of mixed stands is to determine the volumes separately for each species, stem by stem, using volume tables (volume functions), the sum of which equals the current wood stock. Another simple method to determine or forecast the wood stock is the use of height/volume tables prepared for each species, based on the average height of dominant and co-dominant trees in height.

It is widely known that volume is in strong correlation with the average height of the main crop. Another method also requires the measurement of the basal area or crown projection area of the stand as well. Every species of the mixed stand is again regarded as a pure stand. After this, the basal area (crown projection area) is determined and the volume is determined for each species according to their age and yield class using volume tables. Then the volumes are weighted in proportion to the basal area (crown projection area). The sum of these volume values equals the total volume of the mixed stand in question.

The international literature cited in the previous section suggests two further directions concerning the research on the modeling of mixed stands. One direction is the extension of empirical yield models already prepared for pure stands to mixed ones. The other is dynamic modeling based on the physiology of individual trees. However, there is no elaborated methodology available for the latter approach.

Location and method of the studies

Black locust is very often planted together with white poplar on the sandy ridges between the Danube and Tisza rivers in Central-Hungary. The joint proportion of black locust and white poplar exceeds 80% at more than 14.000 hm^2, and 70 % of these stands is less than 20 years old. Having regard to the above facts and the less known yield characteristics of black locust-white poplar plantations, we decided to implement a series of multi-plot trials in this type of mixed plantations, making the study of stand structure and yield factor changes possible over a longer period.

The site class of the forest subcompartment (Kecskemét-Ballószög 20 C) is the following: forest-steppe climate, water-independent hydrological conditions, humus sandy soil with a medium-deep tilth, the physical type of the soil is sand. The area is plain, located below 150 m above sea level.

We have first marked five plots in a 16-years old new planting, in which black locust and white poplar were present in different proportions that were calculated by the number of stems or basal area. The main stand structure and yield factors were determined separately for each species, measured stem by stem, using the volume functions prepared for each species:

For white poplar:

$$v = 10^{-8} d^2 h^1 [h/(h-1.3)]^2 \cdot (-0.4236d \cdot h + 12.43d + 4.6h + 3298)$$

For black locust:

$$v = 10^{-8} d^2 h^1 \cdot [h/(h-1.3)^4 \cdot (-0.6326d \cdot h + 20.23d + 0.0h + 3034)$$

Where: *d* is diameter at breast height, *h* is height.

The ratio of the volumes of the species in the mixed stands and in pure stands (based on volume tables) was determined this way:

$$RV_A = \frac{\text{volume of species "A" in mixed stand}}{\text{volume of species "A" in pure stand}}$$

$$RV_B = \frac{\text{volume of species "B" in mixed stand}}{\text{volume of species "B" in pure stand}},$$

Where:

$RV_{A,B}$ = the ratio of each species by relative volume,

$RTV_{A+B} = RV_A + RV_B$, where:

$RTVA+B$ = the ratio of the tree species by relative total volume.

The volume of the tree species in the mixed stand in proportion to their pure stands was determined on the basis of yield tables edited by Rédei in 1984 for black locust and in 1992 for white poplar.

We have determined the function describing the relationship between the ratio by relative total volume and the proportion (by the number of stems) of the species in question both for black locust and white poplar, as follows:

$RV_{BL} = 0.0286 + 0.0095E_{N\%}$, (r=0.94),

$RV_{WP} = 0.0165 + 0.1334E_{N\%}$, (r=0.96).

Results and conclusions

The main stand structure and yield factors are shown in Table 1. Table 2 contains the ratios by relative volume for each tree species and in total, including the proportion in the stand by the number of stems and the volume of the total stand.

White poplar grows faster in height than black locust if they are planted together (Fig. 1). Black locust could never overgrow white poplar in mixed stands made up of these two species. The difference is particularly impressive if white poplar is scattered in the stand. In this case, poplars are usually found in height class 1 and their proportion does not exceed 20 %. There is a similar tendency in the case of radial growth (Fig. 2). The higher radial growth of white poplar is strongly connected to its greater growing space demand, which is also a particular characteristic.

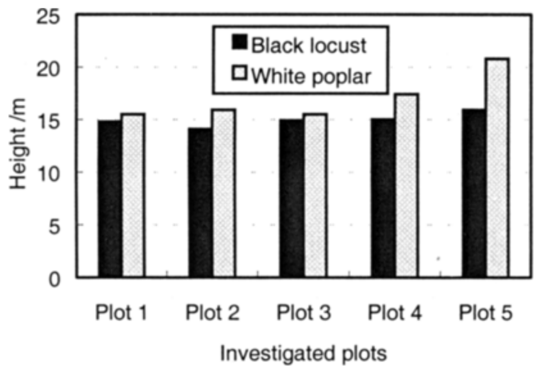

Fig. 1 Mean height of the tree species at the age of 16

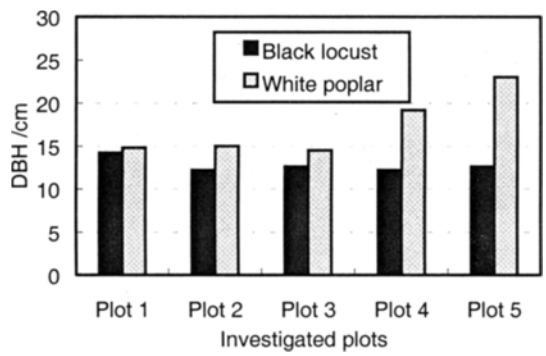

Fig. 2 DBH of the tree species at the age of 16

The changes in the number of trunks of the two species also show the changes in their proportion (Fig. 3). We have tried (and more or less succeeded) to find experimental plots with a similar number of stems and a decreasing proportion of white poplar.

It can be concluded from the comparison of the volume per hectare values that the relative volume surplus of mixed stands at the age of 16 varied between 1.24-1.55 compared to the control, i.e. the volume of pure stands of the species in the mixed stands. The greater the number of white poplar stems was, the greater the volume of the whole mixed stand was (Fig. 4). The ratio by relative total volume in the plot with the highest proportion of white poplar (Plot 1) was 1.55, while the same value for Plot 4 and Plot 5, where the proportion of white poplar was the lowest, it was 1.24 only. The relative volume surplus of white poplar significantly exceeds that of black locust if the number of stems is the same. For example, if there were 50%-50% white poplar and black locust in the stand (calculated by the number of stems) the above surplus ratio would be 0.50 for black locust and 0.82 for white poplar.

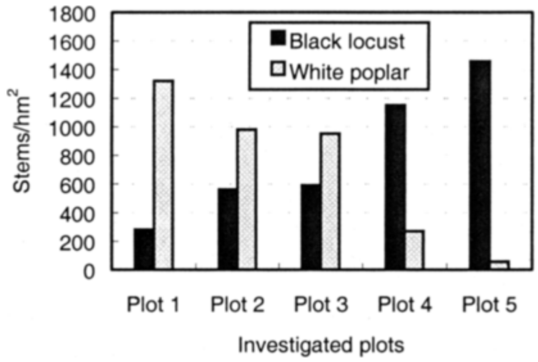

Fig. 3 Stem number of the tree species at the age of 16

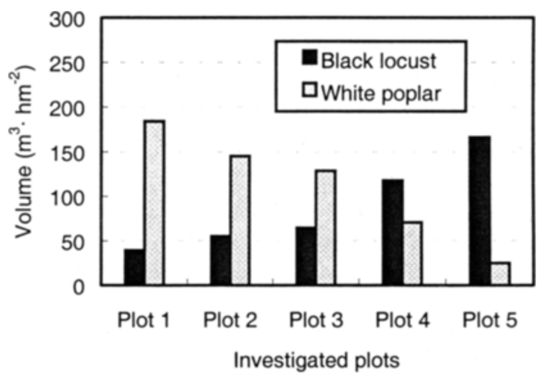

Fig. 4 Volume of the tree species at the age of 16

This trial also proves that if two species have a fast initial growth rate and a similar rotation age, they can be planted in mutually advantageous mixed stands. However, planting (mixing) schemes have to be chosen in such a way that they increase the compatibility of the two or more species in the stand. In addition to the effect on the yield, the method of mixing also affects the execution of intermediate cuttings. For example, if the site is suitable both for black locust and white poplar and they are mixed by single individuals, the dominating species having a larger number of stems is preferred during intermediate cuttings. In the case of mixing by groups, the proportion of the species within the groups and the growth determine which species shall be favoured. The significant effect of the mixing method on the yield requires further studies.

Table 1. The main stand-structure and yield factors of total stands in black locust and white poplar mixed stand at the age of 16

Species factors		Plot 1. Black locust	Plot 1. White poplar	Plot 1. average sum	Plot 2. Black locust	Plot 2. White poplar	Plot 2. average sum	Plot 3. Black locust	Plot 3. White poplar	Plot 3. average sum	Plot 4. Black locust	Plot 4. White poplar	Plot 4. average sum	Plot 5. Black locust	Plot 5. White poplar	Plot 5. average sum
Height, m		14.8	15.5	-	14.1	15.9	-	14.9	15.5	-	15.0	17.4	-	15.9	20.8	-
DBH, cm		14.2	14.8	-	12.2	15.0	-	12.6	14.5	-	12.2	19.2	-	12.6	23.0	-
Number	Stems/hm^2	280	1320	1600	560	980	1540	590	950	1540	1150	270	1420	1457	57	1514
	%	18	83	100	36	64	100	38	62	100	81	19	100	96	4	100
Basal area	m^2/hm^2	4.5	22.6	27.1	6.5	17 4	23.9	7.4	15.7	23.1	13.5	7.8	21.3	18.3	2.4	20.7
	%	16	84	100	27	73	100	32	68	100	63	37	100	89	11	100
Volume	m^3/hm^2	39.1	184.1	223.1	55.1	144.7	199.7	64.2	128.1	192.3	117.5	70.4	187.9	166.0	24.9	190.9
	%	18	82	100	28	72	100	33	67	100	63	37	100	87	13	100

Table 2. Changes in the relative volume of mixed black locust-white poplar stands

Plot number	Tree species	EN %	$V_{\text{whole stand}}$ (m^3/hm^2)	RV_A RV_B	RTV_{A+B}
1	Black locust	18	39	0.25	1.55
	White poplar	82	184	1.30	
2	Black locust	36	55	0.35	1.37
	White poplar	64	145	1.02	
3	Black locust	38	64	0.41	1.31
	White poplar	62	128	0.90	
4	Black locust	81	118	0.75	1.24
	White poplar	19	70	0.49	
5	Black locust	96	166	1.06	1.24
	White poplar	4	25	0.18	
Control	Black locust (Yield table: Rédei, 1984)	100	157	1.00	1.00
Control	White poplar (Yield table: Rédei, 1992)	100	142	1.00	1.00

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